BMC
Neuroscience

Modeling and prediction of conduction delay in an unmyelinated axon

Yang Zhang[1*], Dirk Bucher[2], Farzan Nadim[1]

From Twenty First Annual Computational Neuroscience Meeting: CNS*2012
Decatur, GA, USA. 21-26 July 2012

Conduction delay in axons is a function of the axon morphology, passive membrane properties and voltage-gated ionic currents. Although conduction delay is usually assumed to be constant, indicating perfect temporal fidelity, recent work has shown that the delay of each action potential depends on the prior short- and long-term history of activity in the axon [1]. Violation of temporal fidelity leads to substantial variations in inter-spike intervals which has potential impact on temporal neural activity.

In experiments using the motor axon of the pyloric dilator (PD) neuron of the lobster, *H. americanus*, we measured conduction delay using Poisson random stimuli applied at different mean rates [2]. These measurements showed that the mean value and the variance of

conduction delay increases as a function of stimulus time until these values reach a steady state at about 5 minutes post-stimulation. Even at steady state, conduction delay showed a non-monotonic relationship with stimulus frequency (f_{inst}): it was higher at small or large values of f_{inst} but has a minimum at f_{inst}~45 Hz. Moreover, bath application of dopamine drastically improved the temporal fidelity of conduction delay.

We have constructed a conductance-based model of the PD axon to examine the role of different ionic currents in shaping the history dependence of conduction delay. In addition to the standard Hodgkin-Huxley currents, this model includes a transient potassium current I_A and a hyperpolarization activated inward current I_h, both of which have been characterized in this axon. The
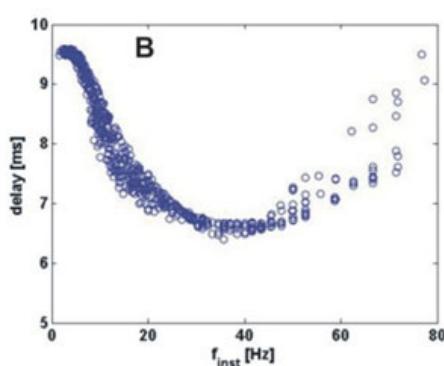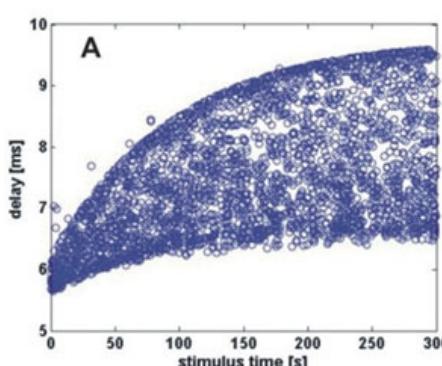

Figure 1 Changes in action potential delay in the model axon in response to 5 mins of Poisson stimulation (mean rate 10 Hz). Compare with experimental data [2]. **A.** Both mean and CV of conduction delay increase slowly in response to activity. **B.** Delay (fifth minute) shows a non-monotonic relationship with stimulus frequency.

* Correspondence: yz83@njit.edu
[1]Dept Math Sci and Dept Biol Sci, New Jersey Institute of Technology, Newark, NJ, 07102, USA
Full list of author information is available at the end of the article

BioMed Central

main effect of dopamine in the biological axon is an increase of I_h which counteracts the activity-dependent hyperpolarization [3], mimicked by adding a Na^+/K^+ pump in the model.

We find that the Na^+/K^+ pump enables the model to reproduce the long-term history dependence observed in the biological PD axon. A pump current with a slow time constant (τ=90 sec) results in a slow increase of the mean and CV of conduction delay with stimulus time (Fig. 1A), and a non-monotonic relationship between conduction delay and f_{inst} (Fig. 1B), as observed experimentally [2]. Additionally, as in the experiments, temporal fidelity is improved as I_h is increased.

Action potential conduction velocity can be approximated by $v = (d / (8R^* R_a C_m^2))^{1/2}$ (d=axon diam, R^*=total memb resistance/unit area at peak, R_a=axial resistivity, C_m=capacitance/unit area [4]. Although this equation accurately predicts the conduction velocity of a single action potential in our model, it fails to the variations in conduction velocity in the presence of the history-dependent effects. This discrepancy is partly due to non-uniform conduction velocity along the axon when active at high rates. We revise the formula to predict the relationship between the conduction delay and total membrane resistance at the action potential peak.

Author details
[1]Dept Math Sci and Dept Biol Sci, New Jersey Institute of Technology, Newark, NJ, 07102, USA. [2]The Whitney Lab for Marine Bioscience and Dept of Neuroscience, University of Florida, St. Augustine, FL, 32080, USA.

References
1. Ballo AW, Bucher D: **Complex intrinsic membrane properties and dopamine shape spiking activity in a motor axon.** *J Neurosci* 2009, **29**(16):5062-5074.
2. Ballo AW, Nadim F, Bucher D: **Dopamine modulation of I_h improves the temporal fidelity of spike propagation in an unmyelinated axon.** *J Neurosci* 2012, **32**(15):5106-5119.
3. Ballo AW, Keene JC, Troy PF, Goeritz ML, Nadim F, Bucher D: **Dopamine modulates I_h in a motor axon.** *J Neurosci* 2010, **30**:8425-8434.
4. Matsumoto G, Tasaki I: **A study of conduction velocity in nonmyelinated nerve fibers.** *Biophys J* 1977, **20**:1-13.